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THE ROLE OF ARTIFICIAL INTELLIGENCE (AI)-ASSISTED QUESTION GENERATION ON PRESERVICE SCIENCE TEACHERS' 21ST-CENTURY TEACHING COMPETENCIES

Yusuf Zorlu

Abstract. *The increasing integration of artificial intelligence (AI) in education highlights the need to explore its impact on preservice science teachers' 21st-century teaching competencies. This study aimed to explore the role of AI-assisted question generation on preservice science teachers' 21st-century teaching competencies. Mixed-methods research design was utilized. This study was participated by 32 preservice science teachers. The "21st Century Skills Teaching Scale", "Tromsø Social Intelligence Scale", "Critical Thinking Disposition Scale", structured interview, and an evaluation rubric were administered as data collection tools. The integration of the generation process of AI-assisted questions was completed in a period of 12 weeks. In findings, the AI-assisted question generation process contributed to the enhancement of preservice science teachers' 21st century skills, social intelligence, and critical thinking disposition. The enhancement of 21st century skills, social intelligence, and critical thinking was concluded that the process of creating questions by utilizing the opportunities offered by artificial intelligence technology was thanks to interaction based on communication with artificial intelligence, cooperation established through group work, and access to up-to-date information through technology. In light of these findings, it could be stated that it will be beneficial to increase the integration of AI into teaching practices in science education.*

Keywords: *21st-century skills, artificial intelligence, critical thinking dispositions, social intelligence, preservice science teachers, science education*

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Introduction

The concept of artificial intelligence (AI) gained a theoretical foundation in 1950 through Alan Turing's work, in which he explored the possibility of thinking machines. It began to take shape as a distinct discipline in 1956, when John McCarthy introduced the term "artificial intelligence" in the lead-up to the Dartmouth Conference (Russell & Norvig, 2020). Since then, AI has evolved into one of the most influential technologies, addressed from various perspectives and described through multiple definitions. In the broadest sense, AI refers to the simulation or enhancement of cognitive abilities—such as reasoning, learning, thinking, and decision-making—typically associated with human intelligence, by computers (Demir, 2004; Luger, 2009; Nilsson, 2010; Wagner, 2024). It can also be characterized as an analytical life cluster designed to mimic human life (Gordon, 2011). According to Poole and Mackworth (2017), AI encompasses the ability to use information acquired from the environment to make decisions and interact with that environment. Overall, AI is a technology actively employed in numerous domains, including process optimization (Salkovska et al., 2024), increasing efficiency (Adams & Thompson, 2025), supporting decision-making processes (Wang, 2021), and delivering personalized environments (Jang & Choi, 2025).

AI has become a critical component, particularly by driving profound transformations in the field of education (Qin & Zhang, 2025). The use of AI in education offers various advantages, such as enhancing student achievement, adapting instructional materials, and supporting teachers in making data-informed decisions (Holmes et al., 2021). In their study on personalized learning, Hardaker and Glenn (2025) have emphasized that AI-based applications accommodate each student's individual learning styles, thereby fostering the development of personal competencies and providing a responsive and structured learning environment that promotes active student engagement. Similarly, Altun (2024) has highlighted that AI significantly contributes to pedagogical processes, such as personalized and adaptive learning, critical and creative thinking, as well as collaborative and simulation-based learning.

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These personalization capabilities render the learning process more adaptive and interactive. Al-Badi et al. (2022) have found that both students and educators hold positive attitudes toward AI in the context of personalized learning. In this regard, it is anticipated that AI may lead to changes in the roles of teachers in the future by assuming responsibilities such as attendance tracking, grade entry, basic knowledge delivery, and the customization of instructional materials (Bayındır, 2023).

In the educational context, AI is increasingly regarded as an innovative tool, particularly in science instruction, where it facilitates students' understanding of complex scientific concepts; supports higher-order cognitive skills (Bayram & Çelik, 2023); and enhances learning motivation and self-efficacy (Huang & Qiao, 2024). These contributions are of significant importance in alignment with the competencies expected from individuals in the 21st century. Referred to as "21st-century skills," these competencies are considered essential for individuals to adapt to the accelerating pace of global change (Gule et al., 2023; Herianto & Purwastuti, 2024). Due to the diversity of existing frameworks, there is no clear consensus on the precise definition of these skills, which are understood to be complex and multidimensional in nature (Chen, 2023). According to the OECD (2005), 21st-century skills fall under three primary categories: the interactive use of tools, the ability to engage with heterogeneous groups, and the capacity to act autonomously. Similarly, the Partnership for 21st Century Skills (P21) classifies them into three overarching domains: "learning and innovation skills", "information, media, and technology skills", and "life and career skills" (Partnership for 21st Century Skills, 2009). Although these skills have been approached from different focal points, they are fundamentally associated not only with students' possession of scientific knowledge but also with their ability to critically assess, apply, and integrate this knowledge through thinking, problem-solving, collaboration, and creativity. According to Scott (2015), the enhancement of 21st-century skills has been critical for individuals to contribute to societal well-being, which requires an accessible educational process that fosters high-level thinking, deep learning, and effective communication. In this regard, pedagogical practices that support the cultivation of 21st-century skills in educational settings are becoming increasingly prominent (Sullivan et al., 2020).

The effective utilization of 21st-century skills is not only contingent upon individual cognitive competencies but also closely linked to components of social intelligence, such as effective communication with others, understanding emotions, and engaging appropriately in social contexts (Wang et al., 2022). According to definitions by Bandura (2002) and Albrecht (2009), social intelligence is a multidimensional competency that enables individuals to develop behavior through interaction with environmental and personal factors, establish harmonious relationships with others, demonstrate empathy, and successfully apply these abilities across various domains of life. In this regard, social intelligence is directly associated with the process by which individuals comprehend the emotions, intentions, and behaviors of others, interpret this information, and develop appropriate social responses. It thus encompasses social awareness and social skills mediated through social cognition (Goleman, 2007; Silvera et al., 2001). As inherently social beings, humans engage and distinguish themselves through their capacity for social intelligence. A review of the relevant literature reveals an increasing emphasis on studies aimed at enhancing students' social intelligence (Platonova et al., 2021; Sailinova et al., 2024).

In the 21st century, one of the key pathways to cultivating qualified and talented individuals is placing critical thinking at the core of educational processes (Cui & Zhao, 2024; Fikriyatii et al., 2022). In this regard, researchers are increasingly emphasizing the significance of critical thinking in education in parallel with ongoing global developments (McPhee & Cox, 2024; Sutoyo et al., 2023). Consequently, the evolving conception of critical thinking emerges as an approach that supports pluralistic, inclusive, and serendipitous learning processes within the context of higher education (Kerruish, 2023). Wan (2022) has highlighted the need for greater efforts to effectively foster critical thinking. Therefore, the inclination toward critical thinking—which aims to develop individuals through approaches that question, analyze, and evaluate modes of thought—holds a vital place in contemporary educational paradigms. Facione (2000) has defined the disposition toward critical thinking as the willingness and tendency of individuals to engage in critical thought, and underscores the importance of nurturing this disposition.

Research Aim and Research Questions

There has been a notable increase in studies exploring the applications of AI in educational contexts. These studies encompass a wide range of dimensions, including teacher and student perceptions, academic achievement, motivation, and accessibility (AlKanaan, 2022; Al Darayseh, 2023; Su, 2022). Research conducted particularly in the field of science education has demonstrated that AI-supported applications effectively enhance learning processes. For instance, the accessible science laboratory developed by Watters et al. (2021) has highlighted the potential of inclusive education by facilitating the participation of visually impaired students in learning environments. Ad-

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ditionally, there are systematic (Almasri, 2024; Jia et al., 2024) and bibliometric (Genç & Koçak, 2024) studies that examine the role of AI in education. These investigations assess the potential of AI technologies and reveal their educational impacts. Similarly, within the domain of science education, significant research has been conducted with a focus on developing 21st-century skills. These studies emphasize the effectiveness of various instructional strategies in enhancing students' 21st-century competencies (Abaniel, 2021; Rethman et al., 2020).

The rapid increase in academic studies focusing on AI and education in recent years highlights the growing importance of examining the contributions of this technology to learning processes (Yun et al., 2025). Moreover, it is anticipated that AI will be used more extensively and effectively in the education in the future. However, at this point, it is evident that research on AI applications in science education remains quite limited. Indeed, in the context of higher education, it is emphasized that creating appropriate learning environments is critical for the effective adoption of AI (Tang et al., 2025). According to Antonenko and Abramowitz (2023), it has been essential that preservice teachers understand what AI is, as well as its role and potential in education, to use it effectively. Without adequate training and support, the full integration of AI into instructional processes cannot be achieved (Yılmaz, 2024). In this regard, there is a clear need for scientific research that contributes to addressing these issues. Accordingly, this study aimed to explore the role of AI-assisted question generation on preservice science teachers' 21st-century teaching competencies. Therefore, the research questions of this study are given below.

- What are the effects of AI-assisted question generation on preservice science teachers' enhancement of critical thinking, social intelligence, and 21st-century skills teaching?
- What are the relationships among preservice science teachers' critical thinking, social intelligence, and 21st-century skills teaching after AI-assisted question generation process?
- What are the preservice science teachers' views regarding AI-assisted question generation process?

In doing so, the study reveals the potential of AI-assisted applications on enhancing preservice teachers' social intelligence, critical thinking, and 21st-century competencies. Furthermore, by examining the multifaceted impacts of this process within the context of teacher education, the study aims to provide an original and timely contribution toward equipping future science teachers with the skills required in the digital age. Within this scope, the study is expected to be among the first of its kind to address the integration of AI-assisted practices in science education in a holistic manner—specifically in relation to social intelligence, 21st-century skills, and critical thinking dispositions—and to serve as a guide for future research in the field.

Research Methodology

Design

This study employed mixed-methods research design. Among quantitative methods, the one-group pretest post-test experimental design was utilized, while the phenomenological research method was adopted from qualitative approaches. In experimental design, participants are assessed with a pretest to measure the baseline status of a variable, followed by an experimental intervention. Subsequently, a post-test is administered to examine the change that occurred (Creswell & Creswell, 2022). The phenomenological research method, built upon a philosophical foundation, aims to explore the essence of individual lived experiences. Data are collected through interviews focused on participants' experiences, and during analysis, either descriptive or interpretative (hermeneutic) approaches are employed to identify common themes across participants' narratives (Creswell & Poth, 2016; Van Manen, 2016). In this study, experimental design was utilized to investigate the effects of the research process on preservice science teachers' critical thinking, social intelligence, and 21st-century skills. The phenomenological research method was employed to explore in detail their experiences and perceived competencies during the process of generation questions using AI. This study was completed in a period of 12 weeks.

Participants

The implementation of this study was structured around the content of the course Applications of Science in Technology. Therefore, preservice science teachers enrolled in the course "Applications of Science in Technology" were considered a suitable sample in terms of both data collection and implementation. Accordingly, a total of 32 preservice science teachers who took the course participated in this study. Participants were between 20 and 22 years of age and included 13 males and 19 females. They were briefed on the aim and procedures of the study, after which they voluntarily agreed to participate by giving informed consent.

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Data Collection Tools

For quantitative data collection, the "21st Century Skills Teaching Scale" (TCSTS), "Tromsø Social Intelligence Scale" (TSIS), and "Critical Thinking Disposition Scale" (CTDS) were used as data collection tools. For qualitative data, a structured interview form (IF) and an evaluation rubric (ERQAI) were utilized. The interview form was distributed to 32 preservice science teachers via Google Documents, and participants were asked to respond to the questions provided in the form.

The 21st Century Skills Teaching Scale (TCSTS) was originally developed by Jia et al. (2016) and later adapted into Turkish by Özyurt (2020). The TCSTS consists of 10 items and uses a 7-point Likert scale. It comprises three subscales: "Utility of Technology (UT)", "Collaboration (C)", and "Innova-tion-Problem Solving (IPS)". In Özyurt (2020) study, the reliability coefficient (Cronbach's alpha) for the overall scale was reported as .82. The reliability values for the subscales were .69 for UT, .69 for C, and .74 for IPS. In the present study, the re-liability coefficient of the overall scale was calculated as .92. The subscale reliabilities were .84 for UT, .77 for C, and .91 for IPS.

The "Tromsø Social Intelligence Scale" (TSIS) was developed by Silvera et al. (2001). The Turkish adaptation of the TSIS was carried out by Doğan and Çetin (2009). The scale consists of 21 items on a 5-point Likert scale. It comprises three subscales: "Social In-formation Processing (SIP)", "Social Skills (SS)", and "Social Awareness (SA)". In the study conducted by Doğan and Çetin (2009), the reliability coefficient (Cronbach's Alpha) for the overall scale was .83. The subscale reliabilities were reported as .77 for SIP, .84 for SS, and .67 for SA. In the present study, the reliability coefficient was calculated as .81 for the overall scale, while the subscale reliabilities were .80 for SIP, .75 for SS, and .71 for SA.

The "Critical Thinking Disposition Scale" (CTDS) was developed by Akın et al. (2015). The CTDS consists of 11 items and is based on a 5-point Likert scale. The scale consists of two subscales: "Critical Openness (CO)" and "Reflective Scepticism (RS)". In the study by Akın et al. (2015), the reliability of the scale (Cronbach's Alpha) was cal-culated as .78; and for the sub-factors, .68 for the CO factor and .75 for the RS fac-tor. In the present study, the reliability of the scale (Cronbach's Alpha) was calculated as .67; and for the sub-factors, .61 for the CO factor and .72 for the RS factor.

The Evaluation Rubric for Questions Prepared with AI (ERQAI) was prepared by researchers using ChatGPT, taking into account the aim and process of the study. The ERQAI was initially generated by the researcher using ChatGPT. Subsequently, necessary revisions were made based on a literature review (Ergün, Güler & **Çorlu**, 2011), and the final version of the rubric was established. The rubric was developed to evaluate the questions prepared by preservice science teachers with the support of AI. It consists of 10 items, each scored between one and four (see Table 1). Preservice science teachers receive a maximum of 40 points and a minimum of 10 points from ERQAI.

Table 1
Evaluation Rubric for Questions Prepared Using AI (ERQAI)

Evaluation Criterion	4 (Excellent)	3 (Good)	2 (Average)	1 (Needs Improvement)
1. Scientific Accuracy	All questions and options are scientifically accurate and based on up-to-date information. No incorrect information is present.	Most questions are scientifically accurate, but minor revisions may be needed.	Several scientific inaccuracies are present; some questions or options may contain incorrect information.	Many scientific errors are present; a significant portion of the questions include inaccurate information.
2. Relevance to the Topic	Questions are fully aligned with the selected science topic and cover it comprehensively.	Most questions are relevant to the topic, though some may not fully reflect it.	Only some of the questions reflect the topic; others may be unrelated or misleading.	Most questions are irrelevant or misleading; thematic integrity is not maintained.
3. Use of AI	AI tools were effectively used to generate creative and original questions.	AI tools were used well, but originality and creativity are limited.	AI tools were used, but contributed minimally. Questions remain basic.	AI tools were insufficiently used; questions appear to be created through traditional means.

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Evaluation Criterion	4 (Excellent)	3 (Good)	2 (Average)	1 (Needs Improvement)
4. Question Difficulty Level	Questions are balanced in difficulty and appropriate for different student levels, including various cognitive levels (knowledge, understanding, etc.).	Questions are generally of appropriate difficulty, but some may be too easy or too difficult.	The difficulty level is inconsistent; some questions are too easy, others too hard.	The difficulty level is inappropriate; most questions are either too difficult or too easy and do not match student level.
5. Validity and Reliability of Assessment	Questions accurately and consistently assess the intended learning outcomes.	Generally valid, though the validity of some questions may be questionable.	Questions partially assess the intended outcomes; a few may be off-target.	Weak validity; questions do not adequately assess the intended learning outcomes.
6. Variety of Question Types	Includes a balanced mix of multiple-choice, open-ended, matching, true–false, etc., assessing diverse thinking skills.	There is some variety, but certain question types may be missing or underrepresented.	Limited variety; mostly reliant on a single type of question.	Almost entirely composed of a single question type; lacks diversity.
7. Feedback and Learning Opportunities	Provides automated feedback via AI and offers learning opportunities after student responses; supports learning.	Some feedback is available, but not all questions provide it.	Feedback is limited, offering learning support for only a few questions.	No feedback or learning opportunities are provided; students may not learn from their mistakes.
8. Structural and Visual Organization of Questions	Questions are clearly structured and presented with visually balanced design; easy to understand and visually engaging for students.	Structure is generally good, though some questions could be better organized; visual design is adequate.	Structural confusion in some questions; presentation or visual layout may be unclear.	Poor structure; disorganized questions with little to no attention to visual design.
9. Applicability of Questions	Questions are designed to be compatible with different learning environments and levels of technology; effective in both digital and print formats.	Generally applicable, though implementation may be difficult in some settings.	Usable only in specific environments or with certain technologies; limited applicability.	Not broadly applicable; usable only under specific conditions.
10. Supporting Student Engagement	Questions are designed to attract student interest and support active participation through rich content and creative formats.	Generally engaging, though some questions may not sufficiently promote participation.	Limited engagement; questions may not stimulate active student involvement.	Fails to support engagement; questions are monotonous and unlikely to motivate students.

The Interview Form (IF) was prepared by the researchers using ChatGPT, taking into account the aim and process of the study. It was designed to identify the experiences of preservice science teachers regarding AI-assisted question generation. The IF consists of six open-ended questions:

1. How do you evaluate the process of preparing questions using artificial intelligence?
2. When you compare this process with previous traditional methods of question preparation, what differences do you observe?
3. What are the contributions of AI applications to the question preparation process? Can you provide examples?
4. Did you encounter any challenges or limitations while using AI during this process? If so, how did you overcome them?
5. Do you consider yourself competent in using AI technology during this process? Do you think you need further training?
6. Do you have any additional suggestions regarding this process?

Intervention

The implementation process and design are presented in Figure 1.

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Figure 1
Implementation Process and Design

1st Week: Preparation & Pre-tests	*•The study was introduced and participants were informed. A WhatsApp group was created for the implementation process. Participants were randomly divided into four groups. Pre-tests of TCSTS, TSIS, and CTDS were administered.*
2nd–3rd Weeks: Orientation & Topic Assignment	•Participants were informed about AI and the use of ChatGPT. Topics related to "Applications of Science in Technology" were assigned to each group by the researchers: – Pharmaceutical and Cosmetic Product Technologies (Group 1) – Water Production Technologies (Group 2) – Stem Cell Technology (Group 3) – Processed Food Technologies and Their Applications (Group 4)
4th Week: Group Work & Presentation Preparation	•Groups conducted research on their assigned topics and collaborated to prepare their presentations.
5th–6th Weeks: Group Presentations	•Each group presented their prepared content in the classroom environment.
7th Week: Question Preparation Using ChatGPT	•Groups prepared questions related to their assigned topics using ChatGPT.
8th–9th Weeks: Presentation of Questions & Feedback	•Groups presented the questions they generated in the classroom. They received feedback from the researcher and other groups.
10th–11th Weeks: Revision of Questions & Evaluation	•Based on the feedback, groups revised their questions and uploaded them to the WhatsApp group. Other groups evaluated the questions using the ERQAI rubric. The Interview Form (IF) was also applied.
12th Week: Post-tests	*•Post-tests of TCSTS, TSIS, and CTDS were administered.*

In the first week, the study was introduced to the participants, and relevant information was shared. Pre-tests of the "21st Century Skills Teaching Scale" (TCSTS), the "Tromsø Social Intelligence Scale" (TSIS), and the "Critical Thinking Disposition Scale" (CTDS) were administered. Participants were then divided into four groups, each consisting of eight preservice science teachers. A WhatsApp group was established to support communication and ensure participation throughout the implementation process.

In the second and third week, participants were informed about artificial intelligence and the use of ChatGPT. Topics related to the applications of science in technology were introduced, and four out of ten preselected subtopics were assigned to the groups. The assigned topics were as follows:

- Group 1: "Pharmaceutical and Cosmetic Product Technologies"
- Group 2: "Water Production Technologies"
- Group 3: "Stem Cell Technology"
- Group 4: "Processed Food Technologies and Their Applications"

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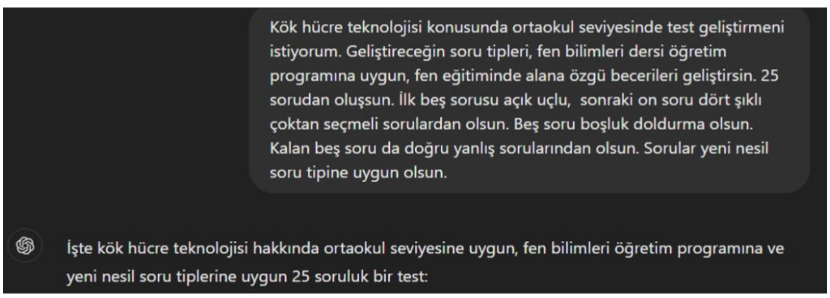
In the fourth week, each group collaborated on their assigned topic over the course of one week (two class hours in total) to prepare a presentation and detailed documents using scientific sources.

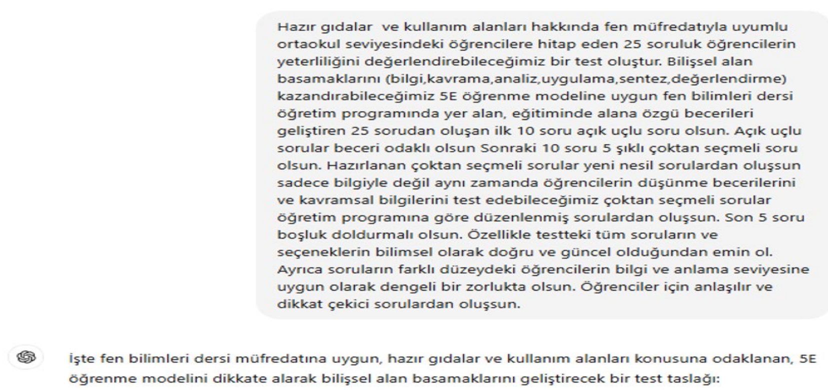
In the fifth week and sixth week, these presentations were delivered during a one-class-hour session in Weeks 5 and 6.

In the seventh week, following the presentations, groups engaged in another week of collaborative work (two class hours) to generate 25 multiple-choice questions using the AI tool ChatGPT, based on the topics they had previously presented. Preservice science teachers used the documents they prepared on the subjects of the "Applications of Science in Technology" course to generate questions in the ChatGPT. This approach helped ensure that the questions produced contained accurate and complete scientific information. While using the free version of ChatGPT, limitations such as the inability to generate visuals were addressed by providing sample question types and revising the generated content through the platform. Through these revisions and examples, questions were enriched with visual elements and diversified content where needed. Examples of how prompts were entered into ChatGPT are presented in Table 2. (Each week included two class hours, totaling 100 minutes.)

Table 2

Examples of Entering Prompts into ChatGPT in Phase 1

<table>
<tr><td>Group 3</td><td>

English Translation I want you to develop a test on stem cell technology at the middle school level. The question types you will develop should be appropriate for the science course curriculum and should develop field-specific skills in science education. It should consist of 25 questions. The first five questions should be open-ended, and the next ten questions should be four-option multiple choice questions. Five questions should be filled in the blanks. The remaining five questions should be true or false questions. The questions should be appropriate for the new generation question type.</td></tr>
<tr><td>Group 4</td><td>

English Translation: Create a test that will evaluate the competence of students with 25 questions that are compatible with the science curriculum about ready-made foods and their usage areas and appeal to middle school students. The first 10 questions consisting of 25 questions that are in the science course curriculum that is suitable for the 5E learning model where we can gain cognitive domain steps (knowledge, comprehension, analysis, synthesis, evaluation) and that develop field-specific skills in education should be open-ended questions. Open-ended questions should be skill oriented. The next 10 questions should be 5-option multiple choice questions. The prepared multiple-choice questions should consist of new generation questions and should consist of multiple-choice questions that will test not only knowledge but also students' thinking skills and conceptual knowledge. The last five questions should be fill-in-the-blank. Make sure that all questions and options in the test are scientifically correct and up to date. In addition, the questions should have a balanced difficulty level that is suitable for the knowledge and understanding levels of students at different levels. They should consist of understandable and eye-catching questions for students.</td></tr>
</table>

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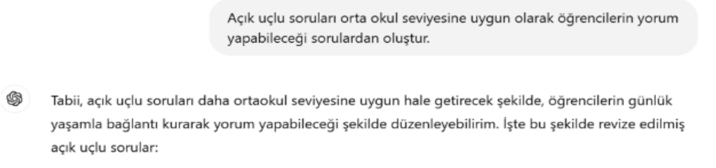
In the eighth week and ninth week, the groups presented both the questions they had prepared and the preparation process during a one-class-hour session (50 minutes). Subsequently, the multiple-choice questions they created were reviewed, and feedback was provided by the researchers and other preservice science teachers.

In the tenth week and eleventh week, based on the feedback, the groups finalized their multiple-choice questions and uploaded them to the WhatsApp group (1 week – 2 class hours). Examples of entering prompts, reviewing, and editing questions generated into ChatGPT are given in Table 3. Then, each group evaluated the questions prepared by the other groups using the ERQAI. At the same time, the researchers also assessed the questions using the ERQAI (1 week – 2 class hours). The preservice science teachers' views regarding the AI-assisted question preparation process were collected through a form created via Google Forms.

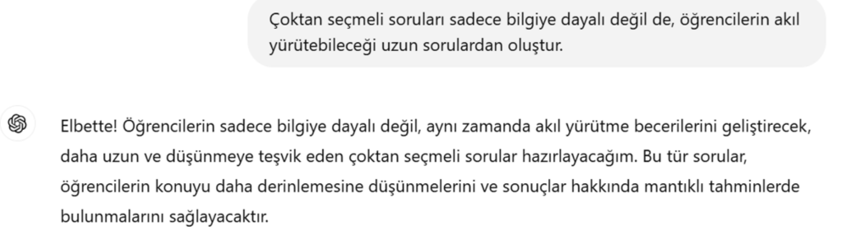
Table 3

Examples of Entering Prompts, Reviewing, and Editing Questions Generated into ChatGPT in Phase 2

Group 1

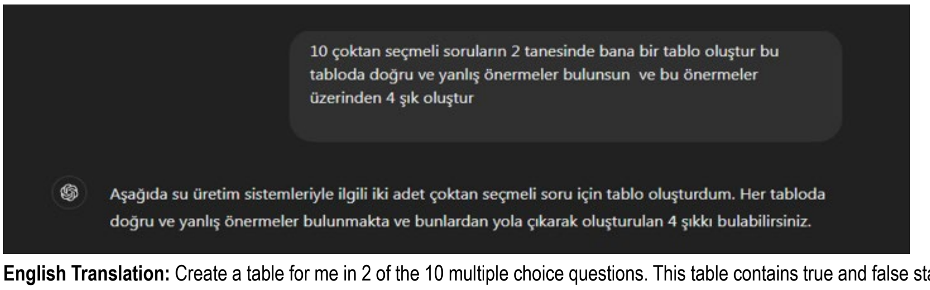


English Translation: Create open-ended questions that are appropriate for the middle school level and that students can comment on.



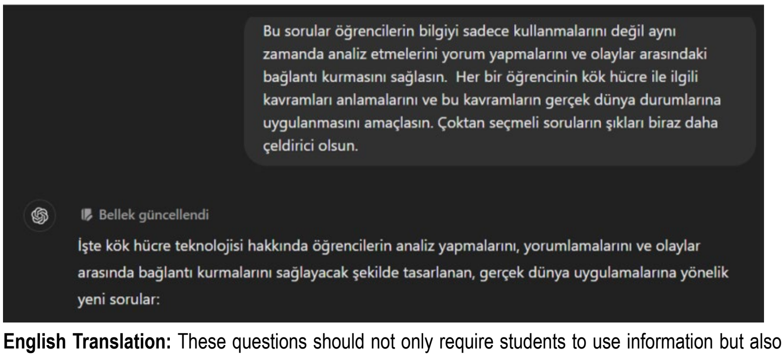
English Translation: Make multiple choice questions longer, not just based on knowledge, but on questions that allow students to reason.

Group 2



English Translation: Create a table for me in 2 of the 10 multiple choice questions. This table contains true and false statements and create 4 options based on these statements.

Group 3



English Translation: These questions should not only require students to use information but also to analyze, interpret, and make connections between events. They should aim for each student to understand stem cell concepts and apply these concepts to real-world situations. The options for multiple-choice questions should be a bit more challenging.

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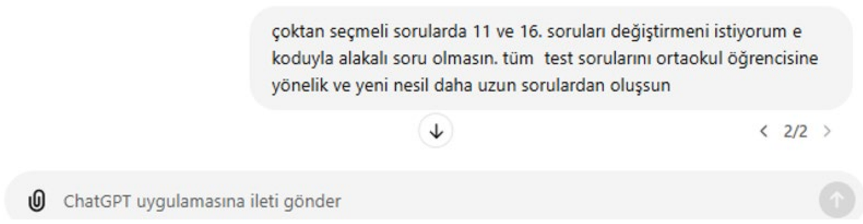
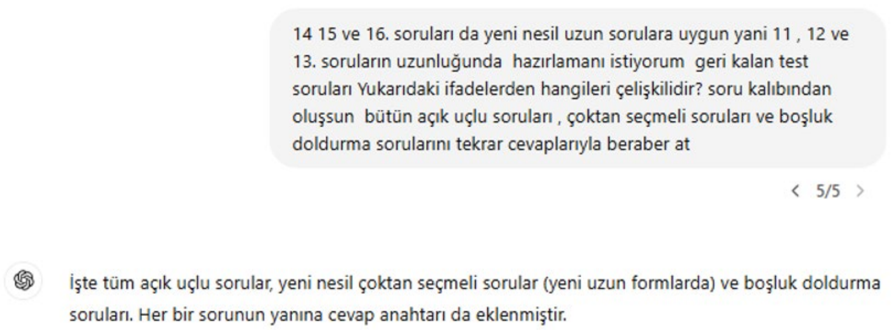
Group 4



English Translation: I want you to change questions 11 and 16 in the multiple-choice questions. There should be no questions related to the E code. All test questions should be aimed at middle school students and consist of new generation longer questions.



English Translation: I want you to prepare questions 14, 15 and 16 in line with the new generation long questions, that is, the length of questions 11, 12 and 13. The remaining questions should consist of the question pattern. Which of the above statements are contradictory? Write all the open-ended questions, multiple choice questions and fill-in-the-blank questions together with the answers again.

In the twelfth week, the post-tests of TCSTS, TSIS, and CTDS were administered.

Ethical Issues

To reduce the potential influence of external variables on the participants, the data collection process was carefully designed. Moreover, ethical approval for the study was granted by the ethics committee of the university affiliated with the second author (Approval Date: 27.11.2024; Meeting No: 2024/11; Document No: 522).

Data Analysis

The qualitative data obtained from the study were analyzed using content analysis. The collaboration was made with an academician (associate professor) who specialized in science education. To determine whether the pretest and posttest data for the TCSTS, TSIS, and CTDS followed a normal distribution, descriptive statistics and normality values were examined. The results are presented in Table 4.

Table 4
Descriptive and Normality Values of TCSTS, TSIS, and CTDS

Descriptive and Normality Values	TCSTS		TSIS		CTDS	
	Pre-test	Post-test	Pre-test	Post-test	Pre-test	Post-test
Mean	51.66	60.56	77.38	92.50	42.31	49.59
Skewness	.284	-.315	-.069	.964	-.575	-.245
Std. Error of Skewness	.414	.414	.414	.414	.414	.414
Kurtosis	-.739	-.450	-.863	.742	-.464	-.415

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Descriptive and Normality Values	TCSTS		TSIS		CTDS	
	Pre-test	Post-test	Pre-test	Post-test	Pre-test	Post-test
Std. Error of Kurtosis	.809	.809	.809	.809	.809	.809
Shapiro-Wilk p	.428	.281	.088	.065	.070	.437

The skewness and kurtosis values of the data obtained from the TCSTS, and its subscales were found to be between -1 and +1, and the ratios of skewness value/skewness standard error and kurtosis value/kurtosis standard error were within the range of -1.96 to +1.96. According to Morgan et al. (2004), skewness and kurtosis values within the range of -1 to +1 indicate normal distribution. Similarly, Can (2014) states that if the ratios of skewness/standard error and kurtosis/standard error fall between -1.96 and +1.96, the data distribution can be considered normal. In addition, normality was tested using the Shapiro–Wilk test, and the results confirmed that the data were normally distributed ($p > .05$). The quantitative data obtained from the TCSTS, TSIS, and CTDS were analyzed using the paired samples t-test.

The data obtained from the rubric were analyzed descriptively. Peer evaluation was conducted within the scope of the research. Each group evaluated the questions prepared by the other groups using the Evaluation Rubric for Questions Prepared with AI (ERQAI). The final scores were determined by calculating the average of the groups' evaluation scores and the researchers' evaluation scores. The data obtained from the interview form were analyzed using content analysis, one of the qualitative data analysis methods, first independently by two field experts (Associate Professors in Science Education), and then collaboratively. When they came together, differing points were identified and finalized based on consensus. To determine the reliability of the qualitative data analysis, the formula "Reliability = Agreement / (Agreement + Disagreement) × 100" was applied (Miles & Huberman, 1994). For the structured interviews, the agreement between the two coders was calculated as: 264 / (264 + 32) × 100 = 89.19%. According to this value, reliability was ensured.

Research Results

Paired samples t-tests were employed to examine whether the differences between preservice science teachers' pre-test and post-test scores on the TCSTS, TSIS, and CTDS were statistically significant. The findings of these analyses are presented in Table 5.

Table 5
Paired Samples t-Test results for TCSTS, TSIS, and CTDS

Scale	Test	*N*	*M*	*SD*	*df*	*t*	*p*
TCSTS	Pre-test	32	51.66	4.76	31	24.535	< .001
	Post-test	32	60.56	6.29			
TSIS	Pre-test	32	77.38	2.39	31	40.047	< .001
	Post-test	32	92.50	3.86			
CTDS	Pre-test	32	42.31	4.06	31	17.882	< .001
	Post-test	32	49.59	2.88			

An examination of Table 5 reveals that there are statistically significant differences in favor of preservice science teachers' the post-test scores on the TCSTS, TSIS, and CTDS (TCSTS: $t_{(31)} = 24.535$, $p < .001$; SIS: $t_{(31)} = 40.047$, $p < .001$; CTDS: $t_{(31)}= 17.882$, $p < .001$).

Paired samples t-tests were conducted to determine whether there were statistically significant differences between the preservice science teachers' pre-test and post-test scores on the subscales of the TCSTS, TSIS, and CTDS. The results are presented in Table 6.

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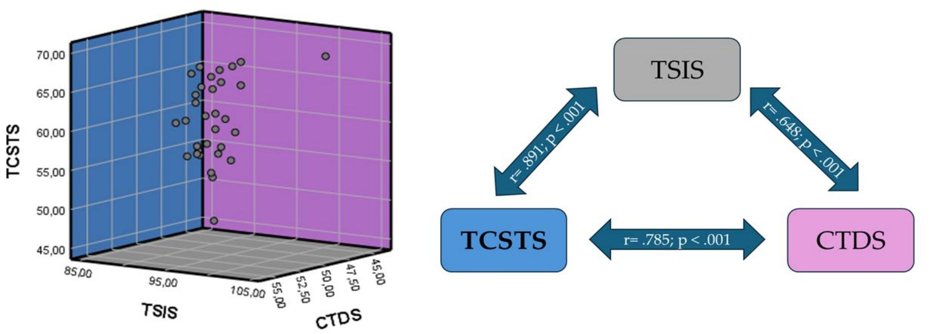
Table 6
Paired Samples T-Test Results for the Subscales of the TCSTS, TSIS, and CTDS

Scale	Subscales		N	*M*	*SD*	*df*	*t*	*p*
TCSTS	UT	Pre-test	32	15.53	1.80	31	8.288	< .001
		Post-test	32	18.16	2.16			
	C	Pre-test	32	16.22	2.00	31	9.435	< .001
		Post-test	32	18.56	2.00			
	IPS	Pre-test	32	19.91	2.05	31	11.143	< .001
		Post-test	32	23.84	2.97			
TSIS	SIP	Pre-test	32	26.50	1.34	31	20.193	< .001
		Post-test	32	33.63	2.28			
	SS	Pre-test	32	23.00	1.24	31	18.922	< .001
		Post-test	32	27.69	1.03			
	SA	Pre-test	32	27.88	1.48	31	9.820	< .001
		Post-test	32	31.19	1.58			
CTDS	RS	Pre-test	32	16.25	1.74	31	5.135	< .001
		Post-test	32	17.91	1.51			
	CO	Pre-test	32	26.06	2.97	31	16.931	< .001
		Post-test	32	31.69	2.09			

An examination of Table 6 reveals that there are statistically significant differences in favor of the preservice science teachers' post-test scores on the subscales of the TCSTS, TSIS, and CTDS (UT: $t_{(31)} = 8.288$, $p < .001$; C: $t_{(31)} = 9.435$, $p < .001$; IPS: $t_{(31)} = 11.143$, $p < .001$; SIP: $t_{(31)} = 20.193$, $p < .001$; SS: $t_{(31)} = 18.922$, $p < .001$; SA: $t_{(31)} = 9.820$, $p < .001$; RS: $t_{(31)} = 5.135$, $p < .001$; CO: $t_{(31)} = 11.143$, $p < .001$).

In order to determine whether there were statistically significant relationships between the preservice science teachers' post-test scores on the TCSTS, the TSIS, and the CTDS, a Pearson correlation analysis was conducted. The findings are presented in Figure 2.

Figure 2
Pearson Correlation Analysis among the Post-Test Scores of TCSTS, TSIS, and CTDS



An examination of the Pearson correlation analysis presented in Figure 2 reveals that there are statistically significant and strongly positive relationships among the preservice science teachers' post-test scores on the TCSTS, TSIS, and CTDS (TCSTS–TSIS: $r = .891$, $p < .001$; TCSTS–CTDS: $r = .785$, $p < .001$; TSIS–CTDS: $r = .648$, $p < .001$).

A Pearson correlation analysis was performed to explore the statistically significant associations among preservice science teachers' post-test scores on the subscales of the TCSTS, TSIS, and CTDS. The findings are presented in Table 7.

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Table 7.
Pearson Correlation Analysis Among the Subscales of the TCSTS, TSIS, and CTDS

Scale	Scale		TCSTS			TSIS			CTDS	
	Subscales		UT	C	IPS	SIP	SS	SA	RS	CO
TCSTS	UT	*r*	1							
		p								
	C	*r*	.749**	1						
		p	p < .001							
	IPS	*r*	.632**	.730**	1					
		p	p < .001	p < .001						
TSIS	SIP	*r*	.681**	.668**	.742**	1				
		p	p < .001	p < .001	p < .001					
	SS	*r*	.778**	.868**	.837**	.772**	1			
		p	p < .001	p < .001	p < .001	p < .001				
	SA	*r*	.504*	.708**	.578*	.697**	.694**	1		
		p	.003	p < .001	.001	p < .001	p < .001			
CTDS	RS	*r*	.797**	.896**	.887	.850**	.914**	.672**	1	
		p	p < .001	p < .001	p < .001	p < .001	p < .001	p < .001		
	CO	*r*	.829**	.868**	.782**	.727**	.869**	.657**	.912**	1
		p	p < .001	p < .001	p < .001	p < .001	p < .001	p < .001	p < .001	

* $p < .05$; ** $p < .01$

An examination of the Pearson correlation analysis in Table 7 indicates that there are statistically significant moderate positive correlations ($r > .30$, $p < .05$) between the SA subscale of the TSIS and the UT and IPS subscales of the TCSTS based on post-test scores. Moreover, strong positive and statistically significant relationships ($r > .60$, $p < .01$) were found among the post-test scores of the remaining subscales of the TCSTS, TSIS, and CTDS.

The results of ERQAI of the questions prepared by preservice science teachers using AI are presented in Figure 3.

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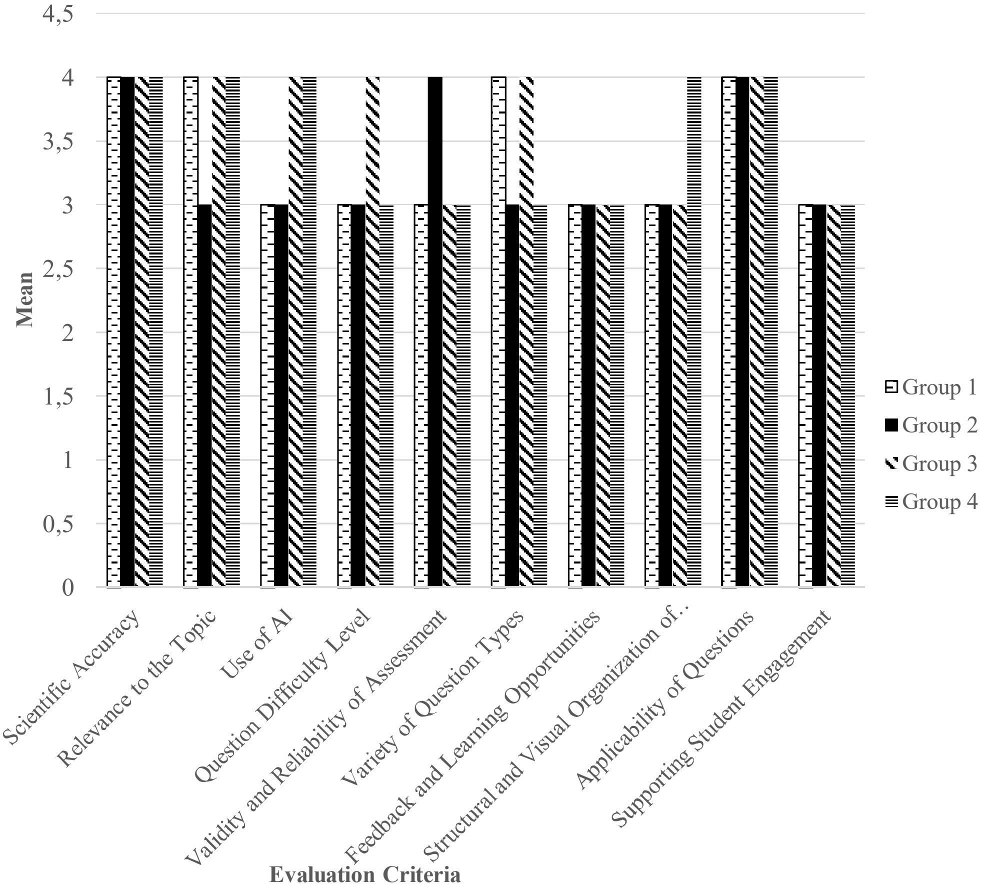
Figure 3
The ERQAI of the Questions Prepared by Preservice Science Teachers Using AI



According to the data presented in Figure 2, the total rubric scores for the questions prepared by preservice science teachers using ChatGPT range between 33 and 36. This indicates that, in general, the arithmetic means of participants' performance across evaluation criteria mostly falls within the 3 to 4-point range. All groups received a score of 4 in the "*Scientific Accuracy*" and "*Applicability of Questions*" categories. In the "*Relevance to the Topic*" category, Group 2 received a score of 3, while the other groups scored 4. In the "*Use of AI*" category, Groups 1 and 2 received a score of 3, while the remaining groups received a score of 4. In the "*Variety of Question Types*" category, Groups 2 and 4 scored 3, whereas the others received 4. For the "*Level of Difficulty*" category, Group 3 scored 4, while the other groups received 3. In the "*Validity and Reliability of Assessment*" category, Group 2 scored 4, and the remaining groups scored 3. For the "*Structural and Visual Organization of Questions*" category, Group 4 received a score of 4, while the other groups received 3. In both the "*Feedback and Learning Opportunities*" and "*Supporting Student Engagement*" categories, all groups received a score of 3. Examples of the questions prepared by the preservice science teachers are provided in Table 8.

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Table 8
Examples of Questions Prepared with the Use of AI

<table>
<tr><th>Group</th><th>Question Type</th><th>Question(s)</th></tr>
<tr><td>1</td><td>True–False</td><td>- To increase the effectiveness of drugs, it is always necessary to take an overdose.
- Cosmetic products can help ensure that the skin appears healthy and smooth.</td></tr>
<tr><td>2</td><td>Multiple Choice</td><td>A. Reverse osmosis is the most effective method for desalinating water.
B. The chlorination process is used to remove heavy metals from water.
C. Filtration removes solid particles from water.
D. Biological purification methods purify water without using chemicals.
Which of the above statements is correct?
a) A and C b) B and D c) A and D d) B and C</td></tr>
<tr><td></td><td>Matching</td><td>Column A Column B
1. Filtration A. Destroys microorganisms without chemicals
2. Ion Exchange B. Removes large particles in water
3. Reverse Osmosis C. Passes water through a semi-permeable membrane
4. UV Disinfection D. Reduces water hardness through ion exchange
Match Column A with Column B.</td></tr>
<tr><td>3</td><td>Informational + Multiple Choice</td><td>Text: Stem cells have the capacity to transform into different cell types. Thanks to this, they can be used to repair diseased organs and tissues.
Question: According to the text, what are stem cells used for?
A) To regulate body temperature
B) To repair diseased tissues and organs
C) To speed up digestion
D) To reduce muscle fatigue</td></tr>
<tr><td></td><td>Informational + Multiple Choice</td><td>Text: Embryonic stem cells can become any cell type, but obtaining them requires destruction of the embryo, leading to ethical concerns. Adult stem cells have more limited capacity.
Question: According to the text, what is the main ethical issue in using embryonic stem cells?
A) Their slow reproduction
B) Embryo destruction required
C) Limited to specific cell types
D) Accessibility to all people</td></tr>
<tr><td></td><td>Table-Based Choice</td><td>The table below lists possible areas of future progress in stem cell therapies. Considering the areas in the table, select the area in which stem cell therapies are expected to make the greatest progress.
Table: Areas of Potential Progress in Stem Cell Treatments
<table>
<tr><td>Area</td><td>Potential Progress</td></tr>
<tr><td>Early detection of genetic diseases</td><td>Medium</td></tr>
<tr><td>Personalization of diet plans</td><td>Low</td></tr>
<tr><td>Repair of broken bones</td><td>Medium</td></tr>
<tr><td>Treatment of serious diseases such as cancer</td><td>High</td></tr>
</table>
A) Early detection of genetic diseases
B) Personalization of diet plans
C) Repair of broken bones
D) Treatment of serious diseases such as cancer</td></tr>
<tr><td>4</td><td>Open-Ended</td><td>1. Elif is preparing a school project on nutrition and researching the role of processed foods. Before asking her classmates whether these foods are healthy, what should she learn? Explain the healthy and unhealthy aspects of processed foods with examples.
2. During grocery shopping, Ali's family reads the labels on packaged foods carefully. Ali is curious about the terms "calorie," "protein," and "carbohydrate." How would you explain these terms and why they are important?</td></tr>
<tr><td></td><td>Multiple Choice</td><td>Scenario: While shopping, Ayşe saw "contains no additives" on a juice label but noticed additional ingredients in the list.
Question: What is the most accurate explanation for Ayşe about label interpretation and additives?
A) The statements on the label are generally marketing strategies; the list of ingredients should be checked.
B) Additives are only natural and always healthy.
C) Additives are always harmful and must be avoided.
D) "No additives" means the product contains no chemicals at all.
E) The color of the package is more reliable than the ingredient list.</td></tr>
</table>

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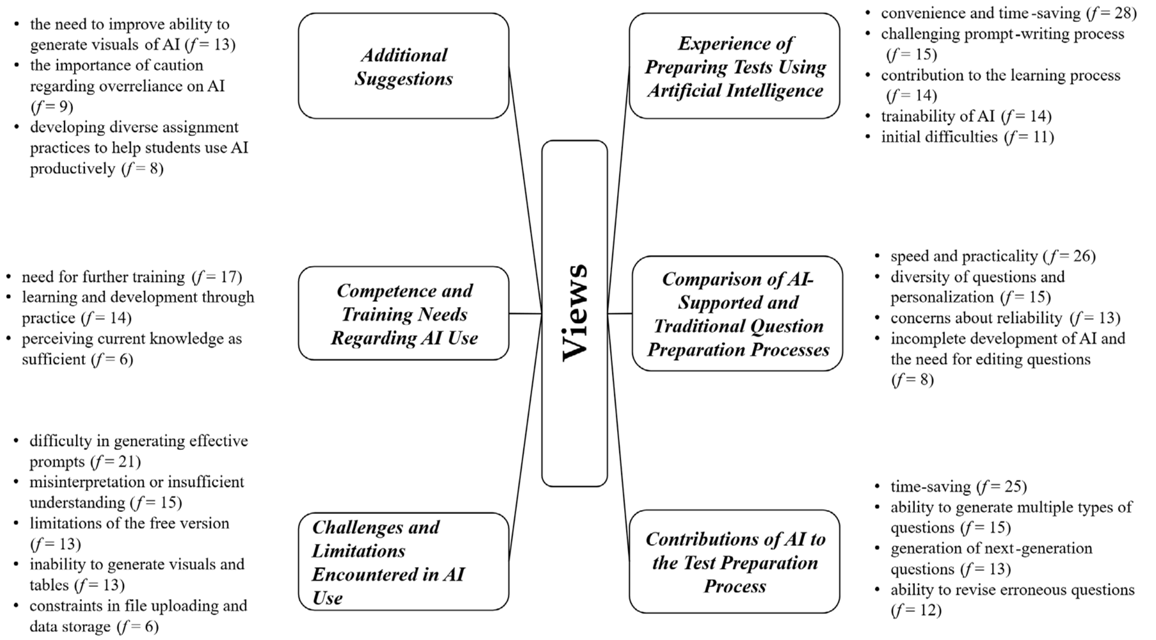
The content analysis of preservice science teachers' views on the generating questions using artificial intelligence is presented in Figure 4.

Figure 4

Preservice Science Teachers' Views on Preparing Questions Using AI



The content analysis of preservice science teachers' views on generating questions using artificial intelligence, as presented in Figure 4, reveals six themes: "*Experience of Preparing Tests Using Artificial Intelligence*", "*Comparison of AI-Supported and Traditional Question Preparation Processes*", "*Contributions of AI to the Test Preparation Process*", "*Challenges and Limitations Encountered in AI Use*", "*Competence and Training Needs Regarding AI Use*", and "*Additional Suggestions*". Within the theme "*Experience of Preparing Tests Using Artificial Intelligence*", the following codes were identified: "convenience and time-saving" (*f* = 28), "challenging prompt-writing process" (*f* = 15), "contribution to the learning process" (*f*= 14), "trainability of AI" (*f* = 14), and "initial difficulties" (*f* = 11). Preservice science teachers stated that AI saves time in question preparation and accelerates the process; that creating effective prompts is challenging and time-consuming; that AI can be trained and requires learning for effective use; and that they experienced difficulties when first starting to prepare tests using AI.

> "*Preparing questions using artificial intelligence saves time. The questions are comprehensive, accurate, and quite strong in terms of variety. AI can generate different types of questions such as open-ended, fill-in-the-blank, multiple choice, survey, and true–false. However, when creating questions with AI, we need to work on developing and refining the questions to a certain level. The more we improve them, the higher the quality becomes. What really matters here is how we ask the questions to the AI. In short, the questions should be phrased in a way that the AI can understand—no spelling mistakes, proper punctuation, and expressed in a clear and detailed manner. The process of preparing questions with AI offers significant advantages in terms of both ease and time.*" (PST15)

Within the theme "*Comparison of AI and Traditional Question Preparation*", the following codes were identified: "speed and practicality" (*f* = 26), "diversity of questions and personalization" (*f* = 15), "concerns about reliability" (*f* = 13), and "incomplete development of AI and the need for editing questions" (*f* = 8). Preservice science teachers expressed that AI is faster and more practical than traditional test preparation methods; however, because AI can generate misleading or convincingly incorrect information, they regarded traditional question preparation methods as more reliable. They also noted that AI is capable of generating various types of questions and adapting them to the appropriate student level, but due to its incomplete development, the generated questions require further editing.

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> "*Personally, I still trust traditional methods more, because AI can make very convincing mistakes. It can be very challenging to identify those errors, but this approach is, in every sense, much more cost-effective. The traditional method may be a bit more laborious, yet it is more reliable*." (PST3)

"*It produces content in a more original and creative manner in a short period. It can generate questions with varying levels of difficulty according to the students' proficiency*." (PST10)

Within the theme "*Contributions of AI to the Question Preparation Process*", the following codes were identified: "time-saving" ($f = 25$), "ability to generate multiple types of questions" ($f = 15$), "generation of next-generation questions" ($f = 13$), and "ability to revise erroneous questions" ($f = 12$). Preservice science teachers reported that, compared to traditional question preparation processes, they were able to create questions in significantly less time; that AI enabled the creation of logic-based and multidimensional questions; and that it could identify faulty questions and provide suggestions for corrections.

> "*When preparing questions, AI tailors them to the students' levels and needs. It offers high diversity and creativity in question types. It generates answer keys and detects incorrect questions. For example, in a test, it identifies improperly worded questions, explains why they are incorrect, and suggests corrections. It can also focus on a topic a student is struggling with and generate questions that progress from simple to complex*." (PST12)
> "*Its contribution to the test preparation process is mainly in terms of saving time and offering multiple question formats. I believe I can now prepare a test in 3 to 5 hours, whereas traditionally this process would take weeks. With AI, it is possible to generate a wide range of question types.*" (PST28)

Within the theme "*Challenges and Limitations Encountered in AI Use*", the following codes were identified: "difficulty in generating effective prompts" ($f = 21$), "misinterpretation or insufficient understanding" ($f = 15$), "limitations of the free version" ($f = 13$), "inability to generate visuals and tables" ($f = 13$), and "constraints in file uploading and data storage" ($f = 6$). Preservice science teachers reported that achieving accurate results often required extensive trial and error; that AI sometimes misunderstood prompts or produced incomplete or incorrect outputs; that its ability to generate visuals and tables for test materials was inadequate; and that there were limitations regarding file uploads and retention of previous data.

> "*Since we used the free version, our access was limited. It was difficult to insert tables or images into the questions*." (PST6)
> "*There were challenges—particularly with prompt creation. Finding the right prompt is difficult. I overcame this through hours of trial and error. A major limitation is that I don't use the premium version of GPT, so I can only enter a new prompt every three hours and have to remind it of the previous ones manually. That's where the difficulty lies.*" (PST21)

Within the theme "*Competence and Training Needs Regarding AI Use*", the following codes were identified: "need for further training" ($f = 17$), "learning and development through practice" ($f = 14$), and "perceiving current knowledge as sufficient" ($f = 6$). Most preservice science teachers indicated a need for more training in order to use AI effectively; they emphasized the importance of hands-on experience in mastering AI use; while some participants stated that their existing knowledge was sufficient for using AI in question preparation.

> "*I definitely need more training on this. I don't think I fully understand the language of AI—or maybe it doesn't understand me.*" (PST1)
> "*I believe I have gained knowledge about AI technology during this process, especially regarding how to prepare test questions. However, I think I could prepare better questions if I received more training.*" (PST27)

Within the theme "*Additional Suggestions*", the following codes were identified: "the need to improve ability to generate visuals of AI" ($f = 13$), "the importance of caution regarding overreliance on AI" ($f = 9$), and "developing diverse assignment practices to help students use AI productively" ($f = 8$). Preservice science teachers emphasized that while AI is becoming increasingly widespread, especially in completing assignments given by instructors or teachers, it is essential to guide students toward using AI collaboratively and meaningfully—rather than as a shortcut. They suggested that similar to the question-generation task, assignments could be designed to encourage active engagement with AI. Additionally, they highlighted the need for critically reviewing AI-generated content and providing precise instructions and ongoing feedback to ensure quality outcomes.

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"*AI is becoming increasingly widespread nowadays. Many students complete their assignments using AI tools. To prevent misuse and encourage productive use of AI, assignments-like the test development task-can be designed to foster collaboration with AI. This way, we can use AI not just to complete tasks, but to understand and benefit from it.*" (PST7)
"*The content we obtain from using AI should always be reviewed. After preparing the questions, we need to give constant feedback to get good results, and we must provide clear instructions to achieve effective outcomes.*" (PST19)

Discussion

In this study, the role of AI-assisted question generation in the enhancement of social intelligence, critical thinking disposition, and 21st-century skills was investigated. In line with this objective, the findings obtained from the research were presented and discussed within the framework of the relevant literature. Based on the results of the study, several recommendations were made for future research.

In the post-test results of the 21st Century Skills Teaching Scale (TCSTS) and its subscales ("Perceived Usefulness of Technology", "Collaboration", and Innovation and Problem Solving"), it was found that the scores of the preservice science teachers' post-test scores were higher than their pre-test scores and that the difference was statistically significant. Based on the findings, it can be stated that the AI-assisted question generation process contributed to the enhancement of the preservice science teachers' 21st-century skills. In this improvement, several factors played a role: the support provided during the question preparation process by utilizing the opportunities offered by AI technology, communication-based interaction with AI, collaboration established through group work, and access to up-to-date information through technology. When the preservice science teachers' views are examined in the IF, it is seen that they stated AI facilitated the question generation process, saved time, provided practicality, allowed for the creation of various types of questions, contributed to the learning process, and enabled the correction of faulty questions. According to their views, the main benefits provided by AI technology in the AI-assisted question preparation process include time saving, practicality, and the creation of a productive learning environment. This process enabled preservice teachers to practically develop key 21st-century skills. The results obtained from the study are supported by relevant literature (Al-Badi et al., 2022; Altun, 2024; Bayram & Çelik, 2023; Hardaker & Glenn, 2025). In the study by Hardaker and Glenn (2025), it was stated that AI-based applications enable the enhancement of students' skills and abilities and provide a learning environment that encourages active participation. Similarly, Altun (2024) emphasizes that AI makes significant contributions to learning, critical and creative thinking, collaborative and technology-supported learning processes in education. Al-Badi et al. (2022) revealed that students have positive attitudes toward AI. The preservice science teachers expressed that through interacting with AI while preparing questions, they were able to generate next-generation questions, contribute to the learning process, revise incorrect questions, and successfully carry out the overall question preparation process. In addition, the innovative and up-to-date nature of AI technology supported the preservice science teachers' problem-solving and innovation skills. Especially during the implementation process, their continuous interaction with ChatGPT and engagement in group work were effective in developing their collaborative learning skills. In the related literature, it is emphasized that AI technology supports cognitive processes unique to human intelligence, such as reasoning, acquiring knowledge, problem-solving, thinking, and decision-making (Bayram & Çelik, 2023; Demir, 2004; Luger, 2009; Nilsson, 2010; Poole & Mackworth, 2017; Wagner, 2024). Group work fosters collaborative learning skills by encouraging equal participation and communication among students with diverse abilities and backgrounds (Slavin, 2022; Zorlu, 2020; Zorlu & Sezek, 2019, 2020). In addition, it is stated that AI provides various advantages to educators in educational settings, particularly in processes such as question generation, visual design, lesson planning, and instructional material development (Holmes et al., 2021). Furthermore, with the help of AI tools, it becomes possible to use time more effectively, increase efficiency, and create goal-oriented learning environments (Adams & Thompson, 2025; Jang & Choi, 2025; Salkovska et al., 2024; Wang, 2021).

In the post-tests of the TSIS and its subscales ("Social Information Processing", "Social Skills", and "Social Awareness"), it was found that the preservice science teachers' post-test scores were higher than their pre-test scores, and this difference was statistically significant. Based on these findings, it can be concluded that the AI-assisted question generation process contributed to the enhancement of the preservice science teachers' social intelligence. During this process, preservice science teachers researched information, shared it within their groups and in the classroom, interacted with ChatGPT, carefully listened to the knowledge and views of others in group work, and benefited from the feedback provided—all of which emerged as important factors supporting the enhancement of social intelligence. In the AI-assisted question generation process, students worked collaboratively in groups.

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Furthermore, their high levels of interest, attitudes, and motivation toward AI encouraged active participation in group work (Al-Badi et al., 2022; Huang & Qiao, 2024). In an AI-assisted process based on group work, participants are also given the opportunity to focus on intra-group interactions. This is considered to provide an appropriate foundation for the enhancement of social intelligence. Goleman (2007) has defined social intelligence as the ability to understand others' emotions and intentions, to enhance appropriate social responses, and to be effective in interpersonal relationships. The preservice science teachers' active involvement in group discussions, consideration of others' views, provision of constructive feedback, and demonstration of empathetic behaviors contributed to the enhancement of their social intelligence. AI-based applications help create learning environments that promote students' active participation and are conducive to active learning (Hardaker & Glenn, 2025; Jang & Choi, 2025; Qin & Zhang, 2025). In the context of social intelligence, the process whereby individuals understand others' emotions, intentions, and behaviors, and engage in effective interaction while developing appropriate social responses, comes to the forefront (Goleman, 2007; Platonova et al., 2021; Sailinova et al., 2024). When the preservice science teachers' views were examined in the IF, they expressed that the AI-assisted question preparation process created interaction-based learning environments, enabled collaborative correction of erroneous questions, and fostered learning through experience. These views support the idea that social intelligence develops through interaction and collaboration during the process. Today, one of the categories of AI software in education is intelligent support for collaborative learning (Luckin et al., 2016). For example, one participant (PST17) stated, "*To use artificial intelligence efficiently, assignments—just like question preparation—can be designed in collaboration with AI,*" highlighting that AI-assisted question generation offers not only individual but also collaborative learning opportunities. In addition, the observed improvement in the social awareness subdimension indicates that teacher candidates developed a more sensitive and empathetic approach while interacting both with AI and their peers. According to the participants, especially the feedback received during the process reinforced behaviors such as being open to different perspectives and valuing their peers' contributions. This finding suggests that AI-assisted learning environments may positively influence not only individual learning outcomes but also learners' social-emotional skills (Zawacki-Richter et al. 2019).

In the post-tests of the CTDS and its subscales ("Reflective Scepticism" and "Critical Openness"), it was found that the preservice science teachers' post-test scores were higher than their pre-test scores and that this difference was statistically significant. These findings indicate that the AI-assisted question generation process improved the preservice science teachers' critical thinking dispositions. This improvement can be attributed to factors such as exchanging ideas through group work, incorporating feedback into the process, revising questions based on different perspectives, questioning the quality of the prepared questions, and critically evaluating one's own experiences. Critical thinking disposition is defined as an individual's willingness and tendency to apply critical thinking (Facione, 2000). Paul and Elder (2019) have emphasized that the foundation of critical thinking lies in the individual's conscious questioning of their own thought processes and the ability to evaluate multiple perspectives. Within the scope of the study, reviewing the questions prepared by other groups using a structured evaluation rubric stands out as an effective practice that supported the enhancement of preservice science teachers' critical thinking dispositions. Moreover, the participants' abilities to formulate accurate prompts, learn by trial and error, perform self-assessment, revise incorrect questions, and identify the challenges encountered during interaction with ChatGPT demonstrate that their critical thinking processes were actively engaged. When the preservice science teachers' views are examined in the IF, these results are supported. One participant (PST12) stated, "*AI detects flawed questions, but it is up to us to understand and correct them*," clearly revealing how the process triggered critical thinking. These findings are consistent with previous studies showing that reflective and collaborative learning environments supported by technology are effective in developing critical thinking (Abrami et al., 2015). Factors such as learning through experience, personal development, evaluating feedback, and recognizing the limitations of artificial intelligence have strengthened preservice science teachers' critical thinking sub-dimensions, namely reflective scepticism and critical openness.

It was found that there were statistically significant and highly positive correlations between the post-test scores of TCSTS, TSIS, and CTDS, as well as their respective subdimensions. The presence of high-level positive relationships suggests that the implementation process in the study contributed to the enhancement of social intelligence, and also simultaneously enhanced domain-specific skills and critical thinking dispositions. In particular, during the AI-assisted question preparation process, individuals' effective use of technology, along with their collaboration efforts, enabled them to actively engage in their social intelligence. In addition, the encouraging nature of AI and the requirement for group work played an important role in the enhancement of social intelligence. At the same time, the participants' ability to critically evaluate the content they prepared contributed to the improvement of

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their critical thinking dispositions. This simultaneous enhancement emerges as a noteworthy finding, indicating that social intelligence, 21st-century skills, and critical thinking dispositions should be considered together in the learning process. The correlations between TSIS, CTDS, and TCSTS support the idea that social intelligence interacts dynamically with cognitive, critical, and digital skills. This finding is also consistent with the characteristics of social intelligence (Goleman, 2007; Platonova et al., 2021; Sailinova et al., 2024). AI-assisted group work may have allowed students to exchange ideas and thereby improve both their social and analytical skills. The relationships between the 21st Century Skills Teaching Scale (TCSTS), the Tromsø Social Intelligence Scale (TSIS), and the Critical Thinking Disposition Scale (CTDS) indicate that 21st-century skills develop in conjunction with social intelligence and critical thinking dispositions. In particular, the use of AI tools in collaborative learning environments may have simultaneously enhanced preservice teachers' ability to integrate new and up-to-date technologies and their capacity for social interaction (Hwang et al. 2020). The correlations between CTDS, TSIS, and TCSTS suggest that critical thinking disposition is connected to both social intelligence and 21st-century skills. Critical thinking requires the consideration of multiple perspectives, inquiry, and conscious thought processes (Facione, 2000; Paul & Elder, 2019). The enhancement observed in this study appears to stem from a combination of planning for conscious thinking through effective use of technology (21st-century skills), increasing social awareness through group work (social intelligence), and valuing different perspectives.

Conclusions and Implications

This study examined the role of artificial intelligence (AI)-assisted question generation on the enhancement of preservice science teachers' social intelligence, critical thinking disposition, and 21st-century teaching skills. The research findings indicate that this process can play a significant role in enhancing the preservice science teachers' 21st-century skills, social intelligence, and critical thinking dispositions. The findings demonstrate that the integration of AI tools, particularly through collaborative group work and interactive engagement with ChatGPT, significantly contributed to the development of these key competencies. The support provided by AI during the question generation process facilitated access to current information, allowed for real-time feedback, encouraged critical reflection, and enhanced collaboration and communication within groups. These conditions collectively created an enriched learning environment where cognitive, social, and technological competencies were simultaneously nurtured. Importantly, the observed strong and positive correlations among the post-test scores of TCSTS, TSIS, and CTDS suggest that these skill domains are interdependent and mutually reinforcing. This highlights the value of designing integrated learning experiences that consider the holistic development of future educators.

Integrating AI tools such as ChatGPT into training programs may enhance preservice science teachers' engagement, reflection, and active participation. Structured activities involving AI-assisted question generation can serve as a practical method to foster 21st-century skills, critical thinking, and social intelligence in preservice science teachers' education. It is anticipated that implementing applications in which artificial intelligence is used not only for question generation but also for the enhancement of various types of instructional materials will contribute significantly to the integration of AI into teaching practices. While this study provides a meaningful contribution to literature in terms of the cognitive and metacognitive roles and effects of AI-assisted processes, further research examining different variables in the future will offer valuable insights into the adaptation of artificial intelligence within learning environments. The AI-assisted question generation process offers significant pedagogical value by promoting the integration of cognitive, social, and digital competencies. As AI technologies become increasingly prevalent in education, harnessing their potential in a pedagogically sound manner will be essential for preparing educators who are equipped to thrive in complex, dynamic, and interconnected learning environments.

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